Benha University **Faculty of Engineering- Shoubra** **Electrical Engineering Department** **First Year communications.**		**1st semester Exam** **Date: 3-01-2016** **ECE111: Electronic Engineering fundamentals** **Duration : 3 hours**

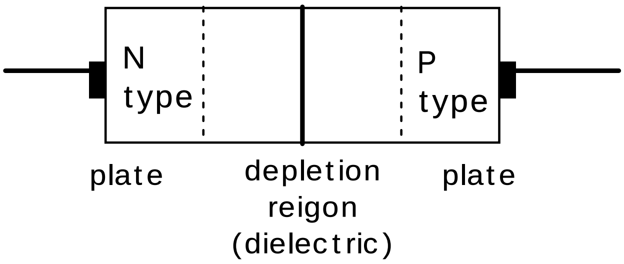
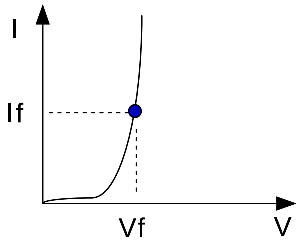
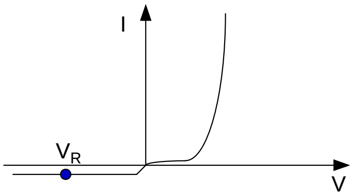
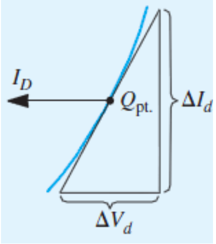
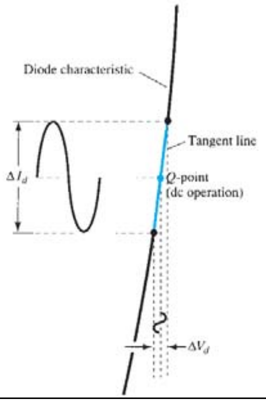
▪ Answer all the following questions ▪ *Illustrate your answers with sketches when necessary*. ▪ The exam consists of two pages.	▪ No. of questions: 5 ▪ Total Marks: 90 Marks ▪ Examiners: Dr. Ehsan Abaas – Dr. Abdallah Hammad

$K=1.38\times10^{-23}$ J/K	$h=6.64\times10^{-34}$ J.s	$q=1.6\times10^{-19}$ C	$m_o=9.1\times10^{-31}$ Kg	$\varepsilon_o=8.85\text{x}10^{-14}$ F/cm
[Si] $n_i=1.5\text{x}10^{10}$ cm^{-3}	[Si] $\varepsilon_{rs}=11.7$	[Si] $E_g=1.12$ eV	[GaAS] $n_i=1.8\text{x}10^{6}$cm^{-3}	[Ge] $n_i=2\text{x}10^{12}$ cm^{-3}

Question 1 (18 marks)

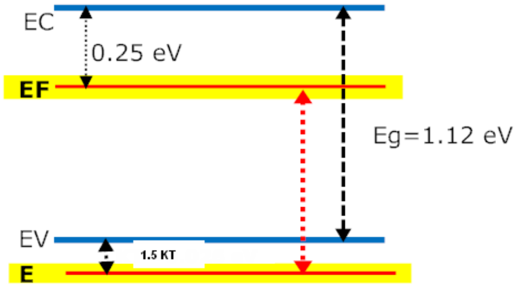
a- Define each of the following (no more than 3 lines each) **(8 marks)**

Depletion region – Depletion Capacitance – Static resistance – dynamic resistance – PIV

Depletion region	When a PN junction is formed, a layer of positive and negative impurity ions, called depletion layer, is formed on either side of the junction. It is also known as depletion-region, space charge region or transition region
Depletion Capacitance	When a PN junction is formed, a layer of positive and negative impurity ions, called depletion layer, is formed on either side of the junction. It is also known as depletion-region, space charge region or transition region. The depletion-layer acts as dielectric. Therefore, these regions act as two plates of a capacitor, separated by a dielectric (i.e. depletion layer) as shown in Fig. 
Static resistance	**Static forward resistance (forward resistance)** It is the ratio between the forward voltage to the forward current and is called also static forward resistance $R_F=\frac{V_F}{I_F}$  **Static reverse resistance (reverse resistance):** It is the ratio between the reverse voltage to the reverse current and is called also static reverse resistance (MΩ) $R_R=\frac{V_R}{I_R}$ 
dynamic resistance	When a small change around the DC operating point the dynamic resistance defined by a tangent line at the Q -point $r_d=\frac{\Delta V_d}{\Delta I_d}=\frac{26\text{ mV}}{I_D}$  
PIV	The peak inverse voltage (PIV) equals the peak value of the input voltage, and the diode must be capable of withstanding this amount of repetitive reverse voltage For Half wave rectifier PIV = Vs(p)

b- In a semiconductor, the Fermi level is 250 meV below the conduction band edge. What is the probability of finding an electron in a state 1.5 KT below the valance band edge E_V at room temperature [Eg=1.12ev]? **(5 marks)**

$$F(E)=\frac{1}{1+e^{\frac{E-E_F}{KT}}}$$



$$E_F-E=\left(E_g-E_1\right)+1.5KT$$

$$E_F-E=1.12-0.25+1.5\times0.026=0.909\text{ eV}$$

$$E-E_F=-0.909\text{ eV}$$

$$F(E)=\frac{1}{1+e^{-\frac{0.909}{0.026}}}=\frac{1}{1+6.55\times10^{-16}}=1$$

c- Silicon at T = 300 K contains an acceptor impurity concentration of N_A = 10^{16} cm^{-3}. Determine the concentration of donor impurity atoms that must be added so that the silicon is n type and the Fermi energy is 0.20 eV below the conduction-band edge. **(5 marks)**

$$E_C-E_F=0.2eV$$

$$E_F-E_i=0.56-0.2=0.36eV$$

$$n=n_ie^{\frac{E_F-E_i}{KT}}=1.5\times10^{10}e^{\frac{0.36}{0.026}}$$

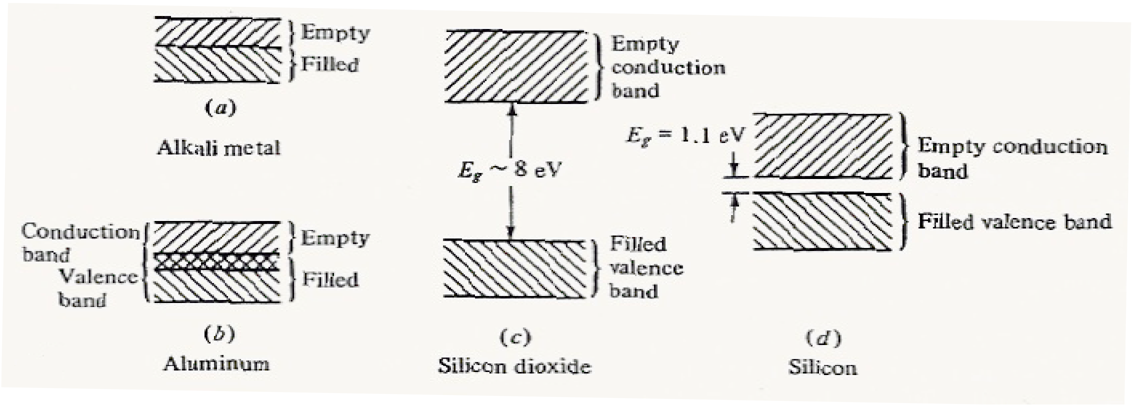
$$n=1.5\times10^{10}\times1.031\times10^{6}=1.5466\times10^{16}$$

$$n=N_D-N_A$$

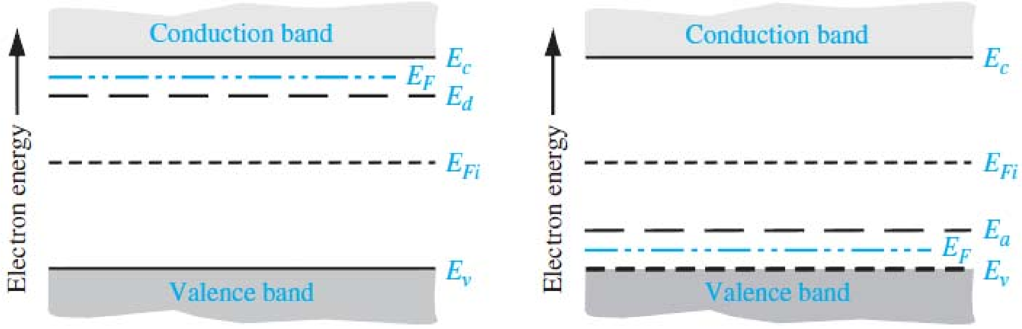
$$N_D=n+N_A=1.5466\times10^{16}+1\times10^{16}=2.5466\times10^{16}cm^{-3}$$

Question 2 **(18 marks)**

a- **Draw the energy band diagram for Insulator – Semiconductor – Metals (indicate all the energy levels on you graph).** **(5 marks)**



For n-type and p-type semicoductors



b- **A silicon semiconductor is in the shape of a rectangular bar with a cross-section area of 100 µm^2. A length of 0.1 cm. and is doped with 5×10^{16} cm^{-3} arsenic atom. The temperature is T = 300 K. given that µ$_n$ =1100 cm^2/V.s and µ$_p$ =300 cm^2/V.s** **(6 marks)**

i- **Determine the current if 5 V is applied across the length.**

ii- **Calculate the average drift velocity of electrons, and holes**

(i)

$A = 100\ \mu m^2 = (100)(10^{-4})^2\ cm^2 \qquad L = 0.1\ cm \qquad N_D = 5\times 10^{16}\ cm^{-3}$

$T = 300K \qquad V = 5\ V \qquad \mu_n = 1100\ cm^2/V.s$

$$R = \frac{\rho L}{A} = \frac{L}{\sigma A}$$

$$\sigma \approx q n \mu_n$$

$$n \cong N_D$$

$$R = \frac{L}{q n \mu_n A}$$

$$R = \frac{0.1}{(1.6\times 10^{-19})(1100)(5\times 10^{16})(100)(10^{-4})^2}$$

$$R = 1.136\times 10^4\ \Omega$$

$$I = \frac{V}{R} = \frac{5}{1.136\times 10^4} = 0.44\ mA$$

(ii)

$$L = 0.1\ cm$$

$$E = \frac{V}{L} = \frac{5}{0.1} = 50\ V/cm$$

$$v_d = \mu_n E = (1100)(50) = 5.5\times 10^4\ cm/s$$

c- The Germanium sample in figure (1) is doped with $5\text{x}10^{15}$ donor atoms per cm^3 at T=300 K. The dimensions of the Hall device are d = 5 x 10^{-3} cm, W = 2 x 10^{-2} cm. and L = 10^{-1} cm. The current I_x = 250 µA, the applied voltage V_x = 100 mV, and the magnetic flux density is B_z = 5 x 10^{-2} Tesla. (n_i=$2\text{x}10^{12}$ cm^{-3}) **(7 marks)**

Calculate:

- i- The Hall voltage.
- ii- The Hall field.
- iii- The carrier mobility.

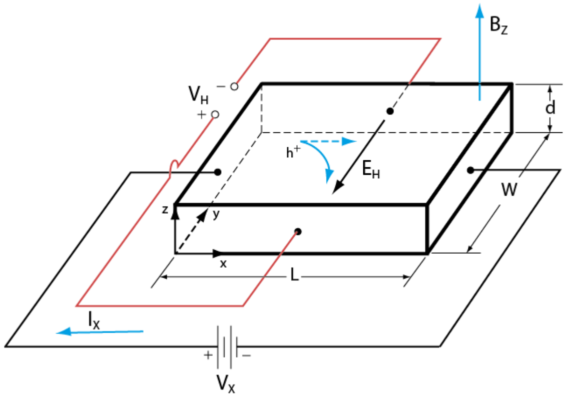


Figure 1

$N_D = 5\times10^{15}$ cm^{-3} $\quad L = 10^{-1}$cm $\quad W = 2\times10^{-2}$ cm $\quad d = 5\times10^{-3}$ cm

$I_x = 250$ µA $\quad V_x = 100$ mV $\quad B = 5\times10^{-2}$ T

(a)

$$\boldsymbol{n \cong N_D}$$

$$n = 5\times10^{15}\ cm^{-3} = 5\times10^{21}\ m^{-3}$$

$$\boldsymbol{V_H = -\frac{I\,B}{q\,n\,d}}$$

$$V_H = \frac{\left(250\times10^{-6}\right)\left(5\times10^{-2}\right)}{\left(1.6\times10^{-19}\right)\left(5\times10^{21}\right)\left(5\times10^{-3}\times10^{-2}\right)}$$

$$V_H = -0.3125\ \text{mV}$$

(b)

$$\boldsymbol{E_H = \frac{V_H}{W}}$$

$$E_H = \frac{-0.3125}{2\times10^{-2}} = 1.562\times10^{-2}\ V/cm$$

(c)

$$\boldsymbol{J = qn\mu_n E}$$

$$\boldsymbol{J_x = qn\mu_n E_x}$$

$$\frac{I_x}{Wd} = qn\mu_n\frac{V_x}{L}$$

$$\mu_n = \frac{I_x\,L}{qn\,V_x\,Wd}$$

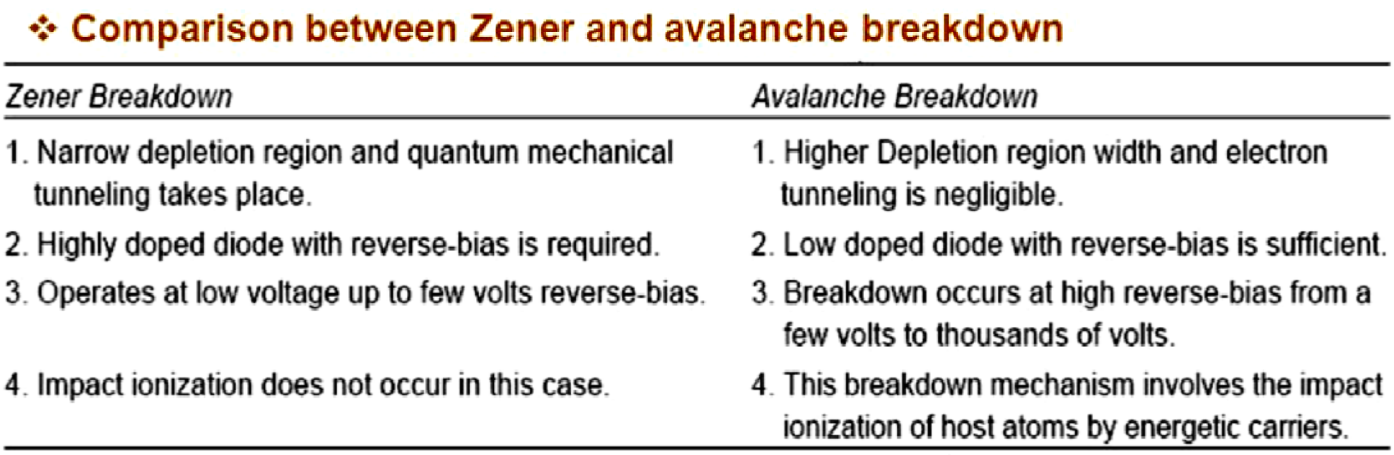
$$\mu_n = \frac{\left(250\times10^{-6}\right)\left(10^{-1}\times10^{-2}\right)}{\left(1.6\times10^{-19}\right)\left(5\times10^{21}\right)\left(100\ \times10^{-3}\right)\left(2\times10^{-2}\times10^{-2}\right)\left(5\times10^{-5}\times10^{-2}\right)}$$

$$\mu_n = 0.3125\ \ m^2/V.s$$

$$\mu_n = 3125\ \ cm^2/V.s$$

Question 3 **(18 marks)**

a- Compare between avalanche break down and Zener break down. **(7 marks)**



❖ **Comparison between Zener and avalanche breakdown**

Zener Breakdown	*Avalanche Breakdown*
1. Narrow depletion region and quantum mechanical tunneling takes place.	1. Higher Depletion region width and electron tunneling is negligible.
2. Highly doped diode with reverse-bias is required.	2. Low doped diode with reverse-bias is sufficient.
3. Operates at low voltage up to few volts reverse-bias.	3. Breakdown occurs at high reverse-bias from a few volts to thousands of volts.
4. Impact ionization does not occur in this case.	4. This breakdown mechanism involves the impact ionization of host atoms by energetic carriers.

Students may use their own words and graphs to identify the difference between Avalanche and zener break down

b- Consider a uniformly doped GaAs pn junction at T = 300 K. The junction capacitance at zero bias is C(0) and the junction capacitance with a 10V reverse bias voltage is C(10). The ratio of the two capacitances is 3.13. Also under reverse bias, the space charge width in to the p region is 0.2 of the total space charge width. Determine V_o N_D, N_A. **(6 marks)**

GaAs T=300 K C(0)/C(10)=3.13 x_p=0.2 W

$$x_p = 0.2W \quad (\rightarrow) \qquad x_n = 0.8W \quad (\rightarrow) \qquad \frac{x_n}{x_p} = 4 \quad (\rightarrow) \qquad \frac{N_D}{N_A} = \frac{1}{4}$$

$$\frac{C(0)}{C(10)} = \frac{C'(0)}{C'(10)} = \left(3.13\right)^2 = \frac{V_o + 10}{V_o}$$

$$V_o = 1.14 \;\; V$$

$$V_o = \frac{KT}{q}\ln\frac{N_D N_A}{n_i^2} = 0.026\ln\frac{4N_D^2}{\left(1.8\times10^6\right)^2}$$

$$N_D = 3.25\times15^{15}\,cm^{-3}$$

$$N_A = 1.3\times15^{16}\,cm^{-3}$$

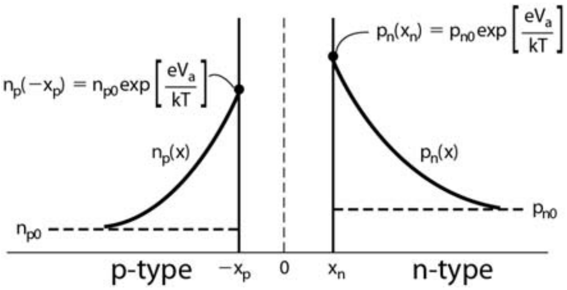
c- For a pn junction, if the reverse saturation current at T=300 K is 1.5x10^{-9} A. What will be its value at T=500 **(5 marks)**

$$I_o(T_2) = I_o(T_1)\times 2^{\frac{T_2-T_1}{10}}$$

$$I_o(500) = 1.5\times10^{-9}\times 2^{\frac{500-300}{10}} = 1.5\times10^{-9}\times1048567 = 1.572864 \quad mA$$

Question 4 **(18 marks)**

a- With the help of figure (2) for the minority carrier distribution in the pn junction under external applied voltage *Va*, Show that $I = I_o(e^{\frac{qV_a}{KT}} - 1)$. **(9 marks)**



$$V_{bi} = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

$$\frac{n_i^2}{N_a N_d} = \exp\left(\frac{-eV_{bi}}{kT}\right)$$

$$n_{n0} \approx N_d$$

$$n_{p0} \approx \frac{n_i^2}{N_a}$$

$$n_{p0} = n_{n0}\exp\left(\frac{-eV_{bi}}{kT}\right)$$

$$n_p = n_{n0}\exp\left(\frac{-e\left(V_{bi} - V_a\right)}{kT}\right) = n_{n0}\exp\left(\frac{-eV_{bi}}{kT}\right)\exp\left(\frac{+eV_a}{kT}\right)$$

$$n_p = n_{p0}\exp\left(\frac{eV_a}{kT}\right)$$

Similarly (Students may start from here):

$$p_n(x_n) = p_{n0}\exp\left(\frac{eV_a}{kT}\right)$$

$$n_p(-x_p) = n_{p0}\exp\left(\frac{eV_a}{kT}\right)$$

$$p_n(x \to +\infty) = p_{n0}$$

The Solution of the continuity equation yields that:

$$\delta p_n(x) = p_n(x) - p_{n0} = Ae^{x/L_p} + Be^{-x/L_p} \qquad (x \geq x_n)$$

$$\delta n_p(x) = n_p(x) - n_{p0} = Ce^{x/L_n} + De^{-x/L_n} \qquad (x \leq -x_p)$$

$$\delta p_n(x) = p_n(x) - p_{n0} = p_{n0}\left[\exp\left(\frac{eV_a}{kT}\right) - 1\right]\exp\left(\frac{x_n - x}{L_p}\right)$$

$$J_p(x_n) = -eD_p \left.\frac{d(\delta p_n(x))}{dx}\right|_{x=x_n}$$

$$J_p(x_n) = \frac{eD_p p_{n0}}{L_p}\left[\exp\left(\frac{eV_a}{kT}\right) - 1\right]$$

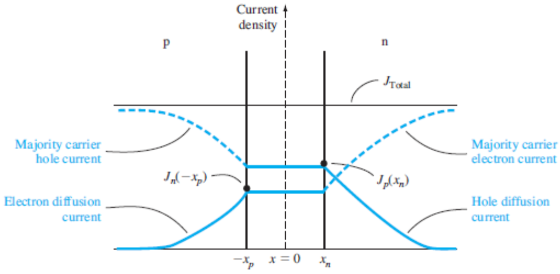
$$J_n(-x_p) = eD_n \left.\frac{d(\delta n_p(x))}{dx}\right|_{x=-x_p}$$

$$J = J_p(x_n) + J_n(-x_p) = \left[\frac{eD_p p_{n0}}{L_p} + \frac{eD_n n_{p0}}{L_n}\right]\left[\exp\right.$$

$$J = J_s\left[\exp\left(\frac{eV_a}{kT}\right) - 1\right]$$

$$J_s = \left[\frac{eD_p p_{n0}}{L_p} + \frac{eD_n n_{p0}}{L_n}\right]$$

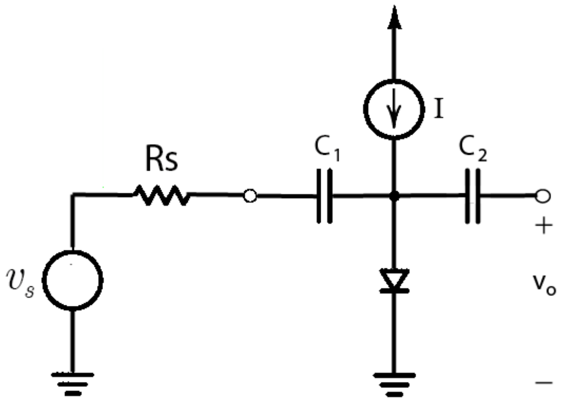
$$J = J_s\left[\exp\left(\frac{eV_a}{kT}\right) - 1\right]$$



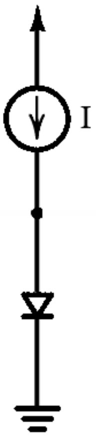
b- In the circuit shown in figure (3), the diode is a silicon diode, I is a dc current of 1 mA, and *vs* is a sinusoidal signal with a peak value of 10 mV. Capacitors C_1 and C_2 are very large, their function is to couple the signal to and from the diode but block the dc current from flowing into the signal source or the load (not shown). Let *Rs* = 1 kΩ. **(9 marks)**

- **i- Determine the v_D, i_D.**
- **ii- Use the diode small-signal model to show that the ac signal component of the output voltage is:**

$$v_o = v_s \frac{V_T}{V_T + IR_S}$$



DC analysis:
Capacitors open circuit

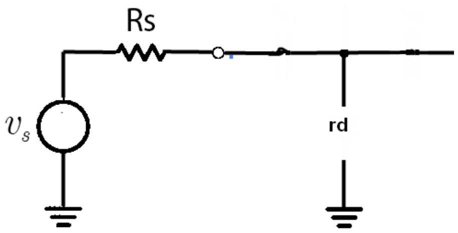


$I_D = I = 1$ mA
$V_D = 0.7$ V

AC analysis:
Capacitors short circuit
DC current source open circuit
diode is replaced by rd

$$r_d = \frac{V_T}{I_D} = \frac{V_T}{I} = \frac{0.026}{0.001} = 26\Omega$$

$$v_d = v_o = v_s \frac{r_d}{r_d + R_s} = v_s \frac{V_T/I}{V_T/I + R_s} = v_s \frac{V_T}{V_T + IR_s}$$



Diode voltage and current

$$v_D = V_D + v_d = 0.7 + v_s \frac{V_T}{V_T + IR_s} = 0.7 + v_s \frac{0.026}{0.026 + 1} = 0.7 + 0.025 \times 10 \times 10^{-3} \sin wt \quad \text{V}$$

$$v_D = 0.7 + 0.253 \times 10^{-3} \sin wt$$

$$i_D = I_D + i_d = 1 + \frac{v_s}{r_d + R_s} = 1 + \frac{10 \times 10^{-3}(V)}{1.026(k\Omega)} \sin wt \quad (\text{mA})$$

$$i_D = 1 + 9.74 \times 10^{-3} \sin wt \quad (\text{mA})$$

Question 5 (18 marks)

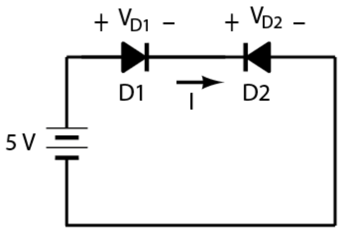
a- Mention the data-sheet specifications for the diode. **(5 marks)**

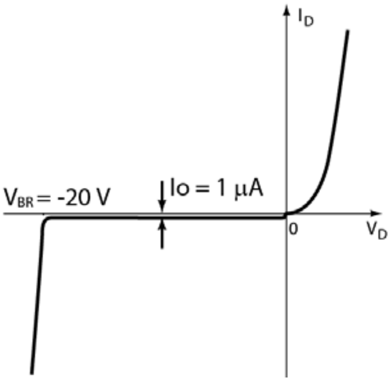
1. The forward voltage V_F (at a specified current and temperature)
2. The maximum forward current I_F (at a specified temperature)
3. The reverse saturation current I_R (at a specified voltage and temperature)
4. The reverse-voltage rating [PIV or PRV or V(BR), where BR comes from the term "breakdown" (at a specified temperature)]
5. The maximum power dissipation level at a particular temperature
6. Capacitance levels
7. Reverse recovery time t_{rr}
8. Operating temperature range

b- For the circuit shown in figure (4-a), both diodes have the same IV characteristics shown in figure (4-b).

i- Identify where are the operating points of both diodes on the characteristics curve.

ii- Calculate numerical values for V_{D1}, V_{D2} and I **(6 marks)**





Diode D_2 is reverse bias while Diode D_1 in the forward blocking region:

$I_{D1}=I_{D2}=I = I_o$ (reverse saturation current) = 1 µA

For the diode D1

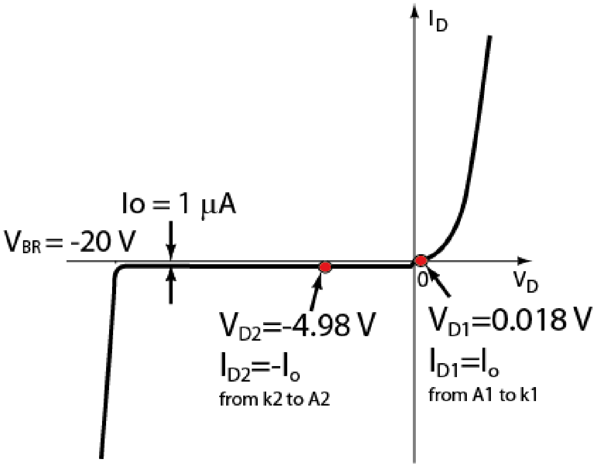
$$I = I_o(e^{\frac{qV_F}{KT}} - 1)$$

$$I_o = I_o(e^{\frac{qV_F}{KT}} - 1)$$

$$e^{\frac{qV_F}{KT}} = 2$$

$$V_{D1} = V_F = \frac{KT}{q}\ln 2 = 0.026\ln(2) = 0.018V$$

$$V_{D2} = -\left[E - V_{D1}\right] = -4.9819V$$

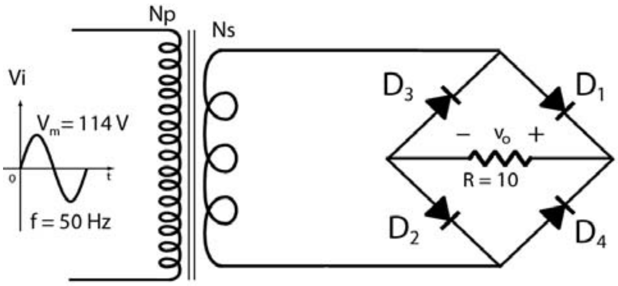


c- For the full wave rectifier circuit shown in figure (5), if the diodes are silicon diodes and N_P:N_S = 10:1 **(7 marks)**

i- Calculate Vs(p), Vo(p), V_{avg}, PIV, f_{out}.

ii- Draw the waveforms I_{D1}, I_{D3}.

iii- Calculate the average values for I_{D1}, I_{D3} and I_L.



(i)

$$V_s(p) = 114 / 10 = 11.4$$

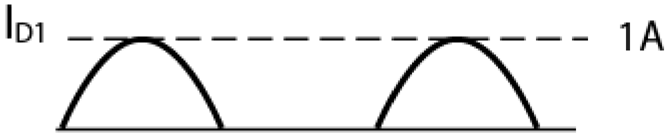
$$V_o(p) = V_s(p) - 2V_D = 11.4 - 1.4 = 10V$$

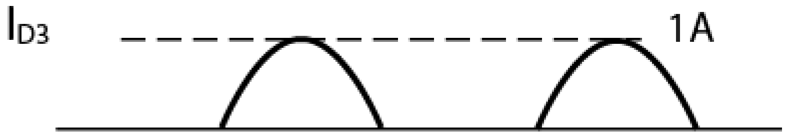
$$V_{avg} = \frac{2}{\pi} V_o(p) = \frac{2}{\pi} \times 10 = 6.36V$$

$$PIV = V_o(p) + V_D = 10.7$$

$$f_{out} = 2 f_{in} = 100Hz$$

(ii)





(iii)

$$I_{D1avg} = I_{D3avg} = \frac{1}{\pi} \frac{V_o(p)}{R_L} = \frac{1}{\pi} \times \frac{10}{10} = 0.318A$$

$$I_{Lavg} = \frac{2}{\pi} \frac{V_o(p)}{R_L} = \frac{2}{\pi} \times 1 = 0.636A$$